Synthesis of attenuation time series for non-GEO satellite paths

ONERA : Jean-Pascal MONVOISIN, Julien QUEYREL, Laurent CASTANET
CNES : Xavier BOULANGER

Introduction

- **Problematic:**
  - Operator and industry need generation of total attenuation (& scintillation) time series for non-GEO applications (telecom or HDTV).
  - Rec. ITU-R P.1853-2 propose a method to synthesize time series of single and multi-site tropospheric impairment on Earth-space paths but only in the case of Geostationary Earth Orbit (GEO).

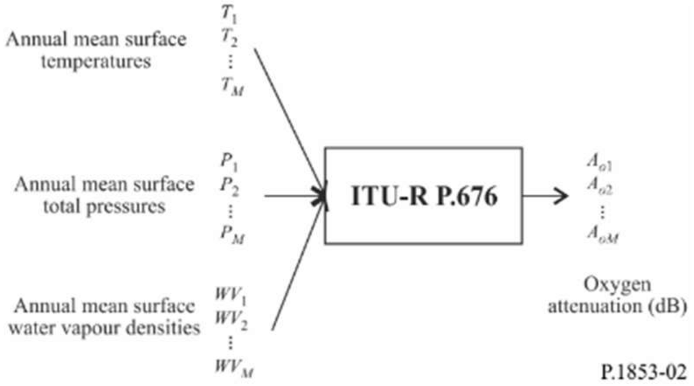
- **Objective**: Adaptation of the existing recommendation ITU-R P.1853-2 to Low and Medium Earth Orbits configuration (LEO & MEO)

Introduction

- **How ?**
  - Non-GEO satellites induces a variation in time of elevation and azimuth angles.
  - Use of elevation-dependent parameters to parameterize the statistical distribution of attenuation:
    - parameterization is analytic in the cases of the attenuation due to oxygen, water vapour, cloud and for tropospheric scintillation,
    - for rain attenuation, a precomputation of distribution parameters for different angles and a linear interpolation of these parameters at the desired angle is used.
  - Then, application of a non-linear transformation to give the final attenuation processes the desired distributions

Distributions parametrization

- **Oxygen attenuation:**
  - Rec. ITU-R P.676-12 convert surface temperature, surface total pressure and surface water vapour density into oxygen height h_O and into oxygen specific attenuation γ_O



  - Direct analytic formula to compute oxygen attenuation A_{Ox} depending on elevation angle θ:

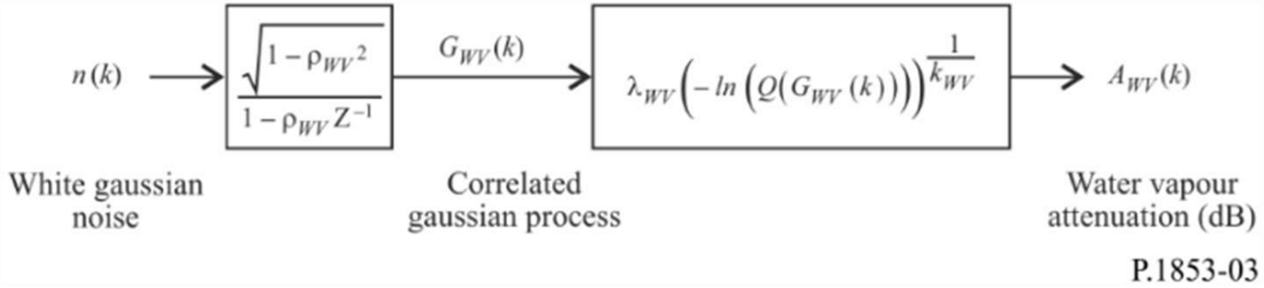
$$A_{Ox}(\theta) = \frac{h_0 \gamma_0}{\sin \theta}$$

Distributions parametrization

- **Water vapour attenuation:**
  - Rec ITU-R P.676 gives the relationship between water vapour attenuation and elevation angle *θ*:

$$A_{WV}(\theta) = \frac{A_{WV}(\theta = 90°)}{\sin\theta}$$

  - According to Rec ITU-R P.1853-2, water vapour attenuation follows a Weibull distribution with scale parameter *λ*, and shape parameter *k*.



The CCDF is given by: $P(A_{WV}(\theta) > A^*_{WV}) = P = e^{-(A^*_{WV}/\lambda)^k}$

Distributions parametrization

- **Water vapour attenuation:**

(1)
$$\ln A_{wv}(\theta) = a\ln\left(-\ln\frac{P}{100}\right) + b$$

Therefore,

(2)
$$\ln A_{wv}(\theta = 90°) = a\ln\left(-\ln\frac{P}{100}\right) + \overset{\mathbf{b'}}{\boxed{b + \ln(\sin\theta)}}$$

Whose solutions are:

(1')
$$\begin{cases} k_{WV}(\theta) = \dfrac{1}{a} \\ \lambda_{WV}(\theta) = \exp b \end{cases}$$

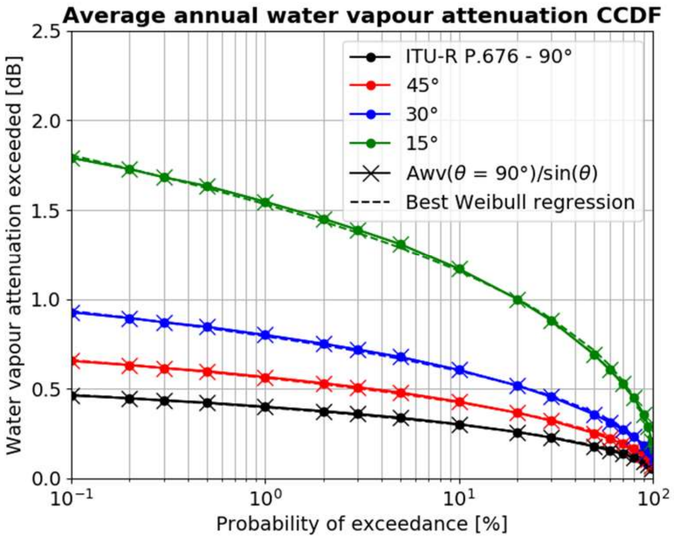
(2')
$$\begin{cases} k_{WV}(\theta = 90°) = \dfrac{1}{a} \\ \lambda_{WV}(\theta = 90°) = \exp b' = \exp b \times \sin\theta \end{cases}$$

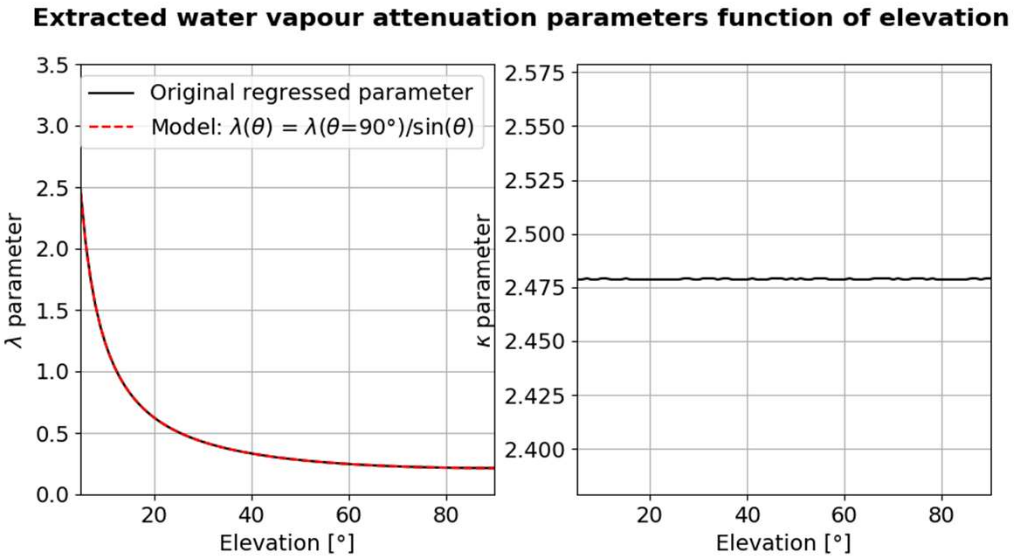
Distributions parametrization

✈Water vapour attenuation:

(1’) and (2’) give:

$$\begin{cases} k_{WV}(\theta) = k_{WV}(\theta = 90°) = \dfrac{1}{a} \\ \lambda_{WV}(\theta) = \dfrac{\lambda_{WV}(\theta = 90°)}{\sin\theta} \end{cases}$$

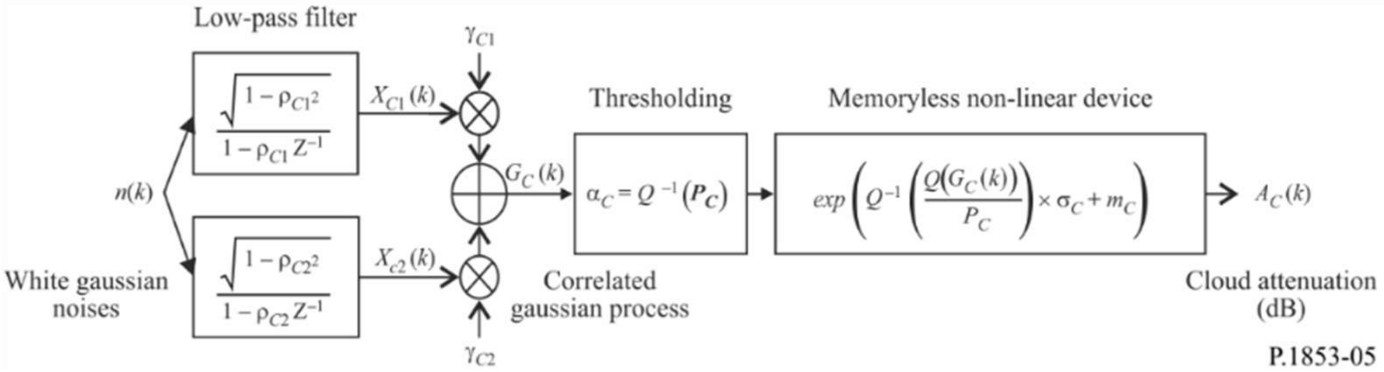

Average annual water vapour attenuation CCDF


Extracted water vapour attenuation parameters function of elevation

Distributions parametrization

✈Cloud attenuation:

- According to Rec. ITU-R P.1853-2, cloud attenuation follows a mixed Dirac-Lognormal distribution:

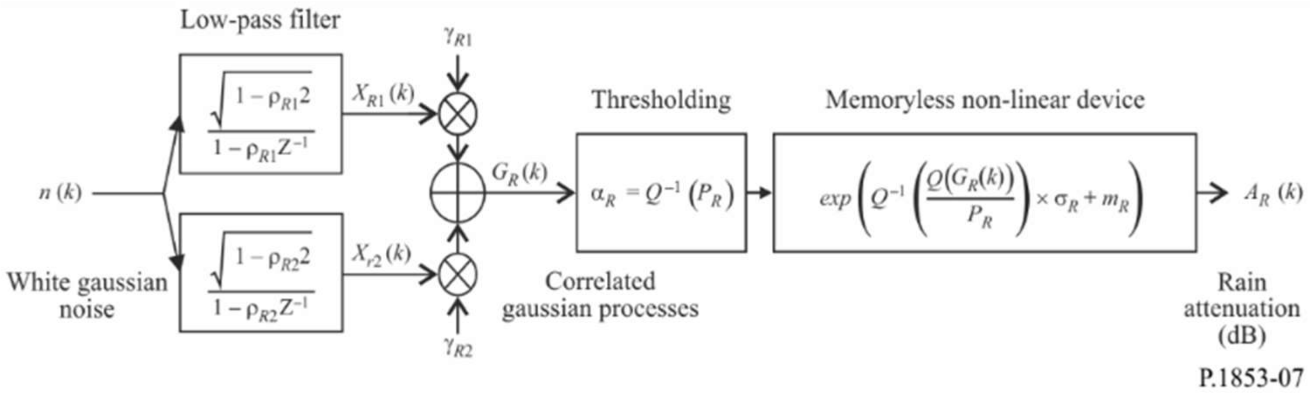


- In Rec. ITU-R P.1853-2, cloud attenuation distribution parameter are linked to integrated liquid water content ones and elevation angle:

$$\begin{cases} m_C = m_{ILWC} + \ln(K_l/\sin\theta) \\ \sigma_C = \sigma_{ILWC} \\ P_C = P_{ILWC} \end{cases}$$

Distributions parametrization

- **Rain attenuation:**
  - According to Rec. ITU-R P.1853-2, rain attenuation follows a mixed Dirac-Lognormal distribution:

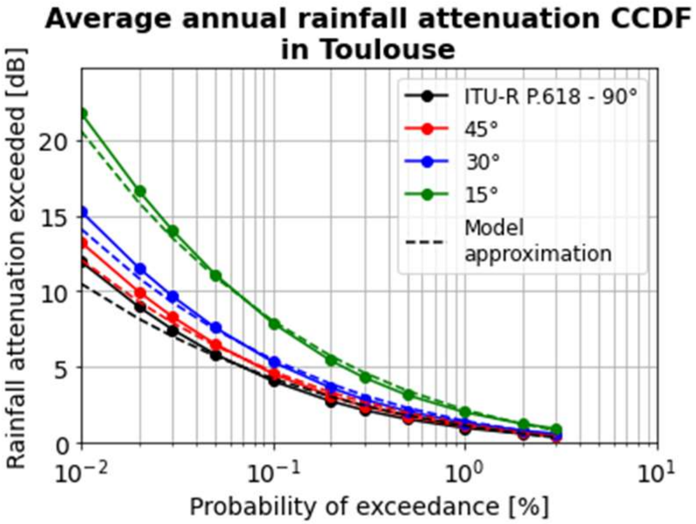


  - No direct parametrization of distribution parameters m_R and σ_R taking into account elevation angle is given

Distributions parametrization

Rain attenuation:

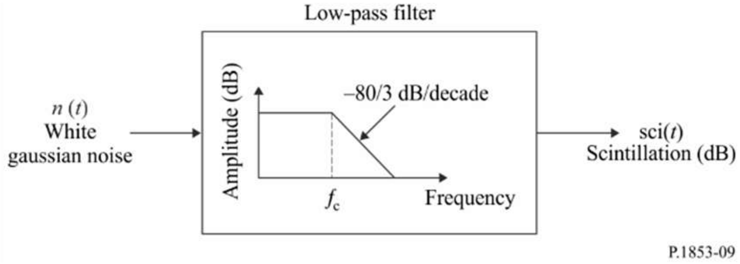
- pre-computation of the log-normal rain attenuation distribution parameter m_R and σ_R for different elevation angles (1° resolution) at the desired location and frequency,
- use of linear regression to interpolate m_R and σ_R at the desired angle during the time series computation.



Distributions parametrization

✈Scintillation:

- ➢In Rec. ITU-R P.1853, scintillation is generated by filtering white Gaussian noise:



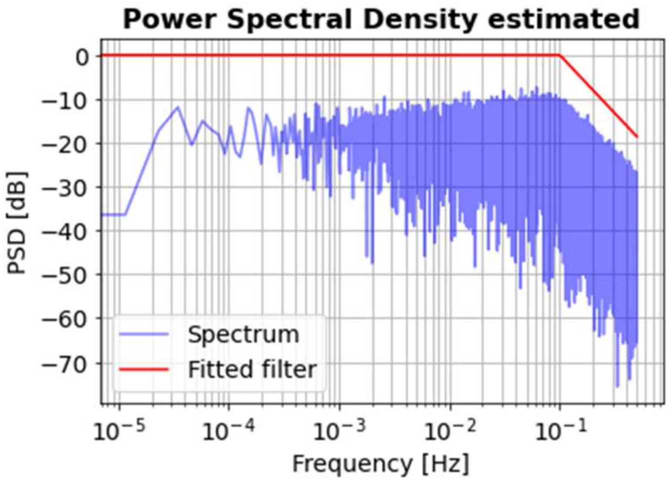
- ➢Rec. ITU-R P. 618-13 gives a model for the statistical distribution of the standard deviation *σ* depending on elevation angle *θ* (*θ* >5°) based on wet component of the refractivity N_{wet}.

$$\sigma = \sigma_{ref} f^{7/12} \frac{g(x)}{(\sin\theta)^{1.2}} \quad \text{with} \quad \begin{cases} \sigma_{ref} = 3.6 \times 10^{-3} + 10^{-4} \times N_{wet} \\ g(x) = \sqrt{3.86(x^2+1)^{11/12} \cdot \sin\left(\frac{11}{6}\arctan\frac{1}{x}\right) - 7.08x^{5/6}} \\ x = 1.22 D_{eff}^2 (f/L) \end{cases}$$

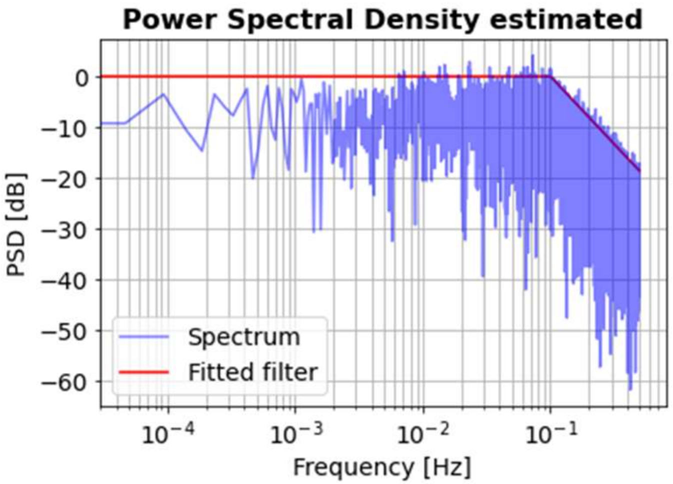
Distributions parametrization

✈Scintillation:

- With this method, there is no change in cutt-off frequency, $f^{8/3}$ roll-off or dynamic. Only an offet is visible on the scintillation spectrum.



GEO simulation

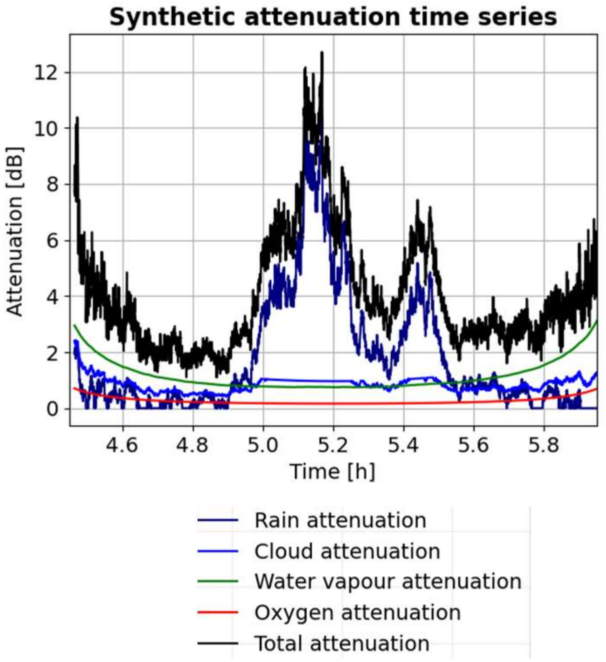


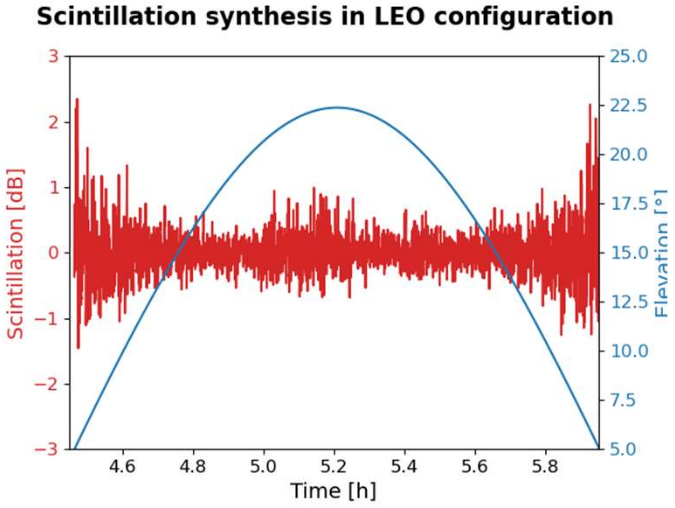
MEO simulation

Time series generation and statistical analyses

- **Example of attenuation and scintillation time series**
  - Simulation at 20.2 GHz with a O3B like satellite in Toulouse (France).

Zoom on one pass during a rain event:





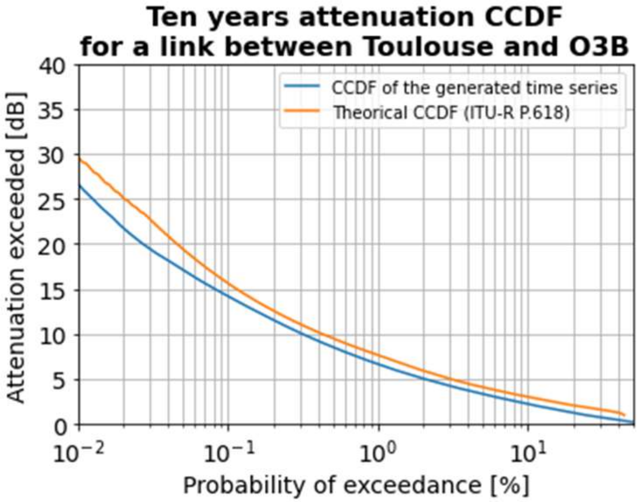
Time series generation and statistical analyses

✈Ten years attenuation CCDF

- Rec. ITU-R P.618-13 gives the theorical CCDF of a non-GEO satellite

$$u = \int_{\theta_{min}}^{90} u(\theta^*)P(\theta = \theta^*)d\theta^* \quad \text{where} \begin{cases} P(\theta = \theta^*) & \text{is the PDF of elevation angles} \\ u(\theta^*) = P(A > A^*|\theta = \theta^*) & \end{cases}$$

- Simulation result:



Conclusion

- **Main results:**
  - An improvement of Rec. ITU-R P.1853-2 for non-GEO link has been presented
  - It is based on parametrization of distribution parameter depending on elevation angle
  - CCDF of time series shows good agreement with theorical one on long terme simulation

- **Limitations:**
  - Single site configuration
  - Temporal correlation is orbit independent
  - No change in scintillation cut-off frequency

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